DEVELOPING A SUBSTITUTION STRATEGY FOR HYDRAULIC STRUCTURES TO MEET THE CHALLENGES OF A NEW CENTURY

by

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ABSTRACT

The Netherlands is situated in a Delta area, in which water management is a very important issue. Water management is necessary to keep the rivers under control, provide fresh water and to protect against flooding. For water management and navigation hundreds of hydraulic structures are built, such as storm surge barriers, ship locks, sluices and pumping stations. They are an integral part of the water network. Most of the hydraulic structures have a projected life time of about 100 years. After this period substitution due to aging becomes necessary.

The hydraulic structures in the Netherlands are aging, so the need for a substitution strategy is growing. Objectives of a very long term (100 years) substitution strategy are to provide a higher quality network, at lower costs for building and maintenance and to be prepared for future developments. Future developments include climate change, demographic and economic developments and changes in de functions of the water system.

This paper discusses the potential benefits of an integrated proactive substitution strategy. Several explorations are carried out to get support for the development of a proper strategy for the whole asset. These are dealing from inventories of the condition of the present asset, learning from others and case studies to a PhD project on *'Very Long Term Development of the Dutch Inland Waterway System'* to provide a sound knowledge base for the desired substitution strategy.

The explorations mentioned above are still in progress. No final results are available yet. But the interests are high, since the total asset value is estimated at 15 billion Euros (price level 2002), which is a lot of money for a small country.

1. INTRODUCTION AND BACKGROUD

The Netherlands is situated in a major delta area in which three important European rivers (Rhine, Meuse and Scheldt) find their way into the North Sea. Water management is necessary to keep the rivers under control, provide fresh water and to protect against flooding. For navigation the delta is a unique area which provides first class access to the European hinterland by means of inland water transport, and has allowed ports like Rotterdam to develop as main gateways to Europe. As a result the Dutch inland water transport sector is amongst the largest and most advanced in the world and leading in Europe. The waterway system can therefore be considered as a key asset for the Dutch economy.

For water management and navigation hundreds of hydraulic structures such as storm surge barriers, weirs, ship locks, sluices and pumping stations have been built. In addition to the hydraulic structures hundreds of bridges have been built to cross the waterways. All those structures are an integral part of the water system and should therefore not be considered as solitary objects. The integral planning of infrastructure is complicated and requires a very long term vision, particularly due to the fact that most of the hydraulic structures have a projected life time of about 100 years, before they need to be substituted due to aging.

At the end of the life time, one-by-one substitution of the structures seems a logical thing to do. However, metaphorically spoken, this would be like replacing all parts of an old car, and delivering a

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good as new old timer. The question is whether buying a new car would not have been a more sensible choice. Translating this to the water system a sound substitution strategy to optimize the possibilities for a system upgrade is proposed. The upgraded system has to meet the challenges of the coming decades, for example climate change and the use of larger vessels[6].

From the above it becomes clear that in order to meet future challenges a more visionary and proactive substitution strategy is desired. This strategy should consider the necessary substitution of the hydraulic structures as an opportunity to reflect on the network at a system level. A proactive approach is likely to improve the functionality and reduce the overall cost levels of the water system.

To develop a visionary and proactive very long term substitution strategy is not a simple task. Several steps, to provide a better insight in all aspects of developing a strategy, are scheduled or taken:

1. An inventory of the hydraulic structures and their expected substitution costs which has already been undertaken for the RINK[7] project. The asset of hydraulic structures in the Netherlands will be described in section 2.
2. In order to learn from others and obtain guidance for the development of a methodology a comparative study will be done with regard to the approach of other institutions inside and outside the Netherlands. The outline of this study is described in section 3.
3. A PhD project on *'Very Long Term Development of the Dutch Inland Waterway System'*, started in March 2009 to provide a sound knowledge base for implementing the desired very long term asset management approach. The study focuses on the transport function of the water system. The outlines and initial findings of the PhD project are described in section 4.
4. A case study involving a small part of the Dutch waterway network, the River Meuse, has been undertaken and will be refined in the future to prove the potential benefits of an integrated proactive substitution strategy. The case study is described in section 5.

All the actions described above will contribute to the development and implementation of the desired methodology and proactive strategy. The process is likely to follow the ADKAR model which stands for: building *awareness*, creating *desire*, developing *knowledge*, fostering *ability* and *reinforce* changes in the organization (Hiatt, 2006). At the moment (spring 2010) the process is still in the phase of building awareness and creating desire and it will not be easy to get the new methods embedded into the organization. For this reason the section 6 will discuss the aspects related to creating awareness and support. Finally in section 7 some concluding remarks will be made.

2. INVENTORY OF HYDRAULIC STRUCTURES AND SUBSTITUTION COSTS

The Dutch delta area is a low laying area in which the Rhine, the Meuse and the Scheldt flow into the North Sea. The rivers Rhine, Meuse and Scheldt, the estuaries Western Scheldt and Eastern Scheldt, the main canals, Lake IJssel, the Wadden Sea and the North Sea form together the Main Water System of the Netherlands (Figure 1).

The hardware of this Main Water System consist of a few parts: bottoms, banks, traffic facilities and hydraulic structures. In this paper we will focus on the hydraulic structures which are planned to function in the system for a very long period, which are not flexible, for which it is difficult to change functionality, and which require high investments. Since the Middle ages the water management depends on some kind of hydraulic structures. However, most of the hydraulic structures we use nowadays have been built in the middle of last century (Figure 1, upper right).

In the Netherlands the Rijkswaterstaat, part of the Ministry of Transport, Public Works and Water Management, is responsible for the operation and maintenance of the Main Water System. The system has several functions (Rijkswaterstaat, 2009):

- Basic functions: safety against flooding (due to high river discharges and storm surges), clean, sufficient and healthy water
- Navigation function (main user function): quick, reliable and safe traffic, for al waterway users
- Other user functions: such as drinking water, irrigation water for agriculture, fisheries, recreation, swimming water.

[6] One of the challenges is how to deal with climate change. The 2nd Delta Commission (2008) has advised the government about this subject. The recommendations comprise safety against flooding as well as water supply in dry periods. The government will use these recommendations to determine the measures to be taken. The results are expected in 2015.

[7] Risico Inventarisatie Natte Kunstwerken, in English: Risk Inventory Hydraulic Structures.

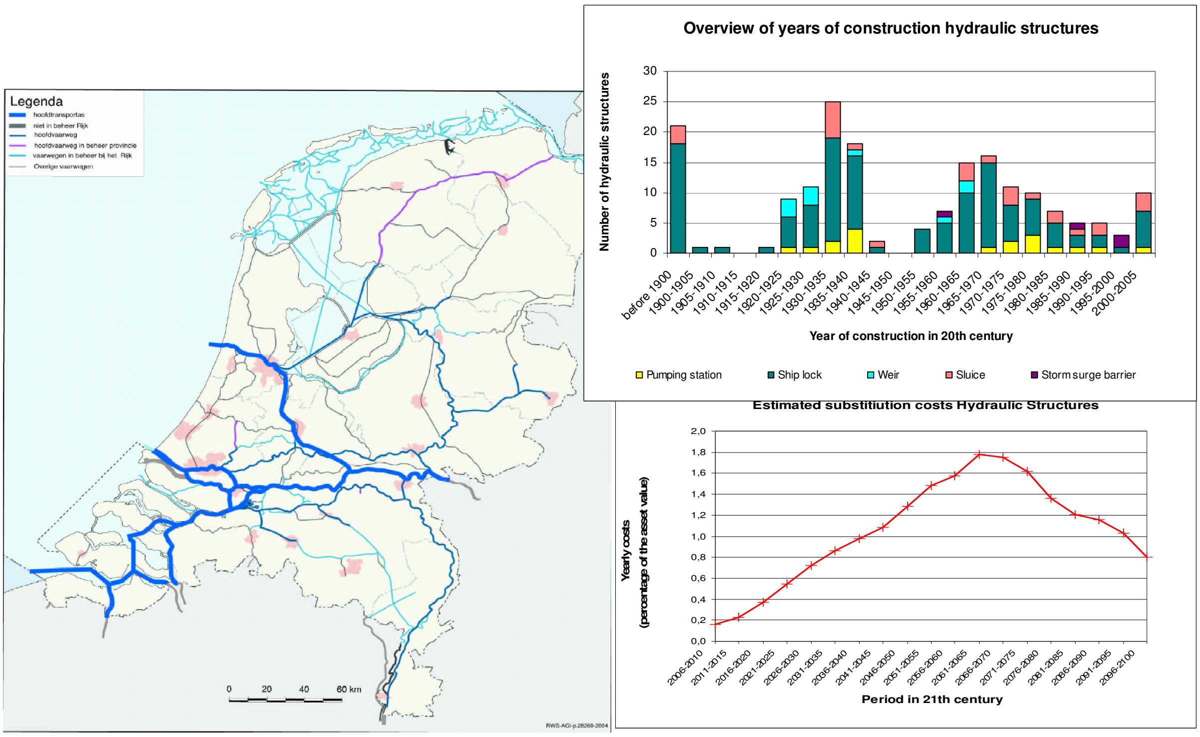

Figure 1: Dutch Main Water System, and quantity, age, and estimated substitution costs of the asset of hydraulic structures

In the Main Water System the most hydraulic structures contribute to the basic functions as well as to navigation. The amount of hydraulic structures in the Main Water System varies a little bit in time but recent numbers figure out (updated from Rijkswaterstaat, 2002):

- Safety and drainage: 4 storm surge barriers, 20 pumping stations, 15 sluices;
- Navigation: 119 ship locks, 10 weirs, 173 mooring facilities
- Cross connections: 168 fixed bridges, 108 movable bridges

Figure 2 shows photographs for different types of hydraulic structures. The total asset value of the assessed structures is estimated at 15 billion Euros (price level 2002). Figure 1 lower right shows the estimated percentage costs for substitution in time, based on the projected life time per construction part, roughly up to 100 years. Due to climate change (floods and draughts) and developments in the use of the waterways (larger vessels, more recreation demands, agricultural, drinking and industrial water supply), the life-time of the constructions will be reduced. Therefore the peak in substitution costs is expected to occur earlier than shown in Figure 1 lower right. The follow-up of the advice of the Delta Commission (2008) and the developments in safety assessment may lead to advance the end of life-time of hydraulic structures as well.

The number of hydraulic structures, the corresponding substitution costs and the advance of the expected end of life-time, justifies exploring a strategy for substitution as a part of asset management.

3. PRACTICAL APPROACH: LEARNING FROM STRATEGIES ELSEWHERE

The situation in the Dutch water system is not unique. Other countries and organisations have to deal with the same asset management assignment. A long term system approach should be combined with a more practical approach which contributes to preparations of applicable decisions for the management of today.

In order to learn from other organisations a comparative study will be carried out. This study will start with some explorations, with the objective to find key elements which play a role in decisions for substitution, and to get an inventory of possible and practical strategies.

Figure 2: Photographs of several types of hydraulic structures in the Main Water System.

A first exploration consists of several investigations of the management of substitutions:

- in the past. In the past the water system evoluated stepwise to the use of today. Substitutions on a large scale are rare. However, it is important to investigate past developments and learn from the experiences in the past. Possibly the maintenance approach gives starting points as well.
- by other countries with a significant quantity of hydraulic infrastructure.
- by other (regional) authorities, like water boards with respect to their regional asset, or city councils with respect to sewer infrastructure.
- by large (semi-private) companies with (social) responsibilities in the operation and maintenance of infrastructure like the railway, drinking water supply, electricity supply, etc.
- by other large companies for which their operation is depending on infrastructure, like the airport and harbour companies.

Last part of the first explorations is to deduct from the investigated strategies the common elements, and to investigate why other elements don't belong to the common ones.

Another exploration consists of the use of the case study Meuse (section 5) to involve stakeholders in the process. Based on the discussion, the interests of the stakeholders and the results of above mention explorations, the case study has to be more or less extended.

Based on the explorations a proposal will be made for this practical track to prepare a strategy oriented on decisions for the coming years, and for development of a strategy based on a long term system approach.

4. RESEARCH: DEVELOPMENT OF A LONG TERM SYSTEM APPROACH

4.1 A proactive substitution strategy

In the introduction it was recognized that there is a desire for a more visionary and proactive long term substitution strategy within the Rijkswaterstaat organization. A PhD project was considered an ideal way to develop a knowledge base and prepare for the development of the desired proactive substitution strategy. The outlines of the PhD project are described in this section.

The PhD project is a first step to develop knowledge on the subject and demonstrate the feasibility of taking very long term effects into consideration in the day to day policy making process. The feasibility can be demonstrated by analyzing a case study for a single (transport) function of the waterway system. After the proof of concept an evaluation method, vision and proactive strategy for the very long term development of the infrastructure can be developed. If the evaluation method for the transport function works satisfactory the method can be improved and scoped-up to cover all aspects of infrastructure asset management.
The perceived path for the full development of the proactive strategy is likely to require at least a decade and involves the following steps:

1. Demonstrate the feasibility of taking very long term developments (on the waterway system) into account in the decision making process.
2. Develop an evaluation model, vision and proactive strategy for the very long term development of a single (transport) function of the water system.
3. Develop an evaluation model, vision and proactive strategy for the very long term development of all identified functions of the water system.
4. Develop an evaluation model, vision and proactive strategy for the very long term development of both road and water system infrastructure.

Only the first to steps will be addressed in the PhD project.

4.2 Scientific context and relevance of PhD project 'long term development of waterways'

In this paragraph an overview will be given of the (literature) research done for the PhD project so far. The scientific relevance and perceived challenges of the PhD project will be addressed.

4.2.1 Including very long term effects is a logical next step in asset management

Very long term forecasts as well as methodologies and strategies to deal with *deep uncertainty*[8] are increasingly gaining interest. Including very long term developments into asset management policies is a logical next step that has already been identified a decade ago by Plantey (1999). He presented a similar case of asset management for the French hydro agricultural water infrastructure. In this case the annual renewal costs for the infrastructure were expected to grow from 20 million FFR in 2000 to 150 million FFR in 2060. The study concluded that: *"[…] a long term management strategy can not really be applied if little effort is made to obtain objective data on the real condition of the system and to ensure its adaptation to the changing needs of its customers. Such efforts need not to be excessive and, if applied consistently and permanently, will prove to be very productive in optimizing the management procedures."* Though the wording of this conclusion is a bit vague Plantey probably meant that long term management strategies can be applied on a high level of aggregation and therefore require relatively little efforts compared to detailed strategies prepared for the short and medium term. Despite promising benefits very long term asset management is still to be developed

[8] Deep Uncertainty is defined as a condition in which analysts do not know or the parties to a decision cannot agree upon (1) the appropriate conceptual models to describe interactions among a system's variables, (2) the probability distributions to represent uncertainty about key parameters in the models, and/or (3) how to value the desirability of alternative outcomes (Lempert, Popper, and Bankes, 2003, p. xii).

and hardly practiced. Research is required to define clear methodologies for dealing with very long term asset management.

4.2.2 New policy methods for dealing with deep uncertainty are available

To implement very long term planning horizons and deal with high uncertainty flexible state of the art policies will have to be adopted. No longer will it be possible to outline a policy on the basis of the optimization of a given trend or the selection of robust solutions amongst a number of likely future scenarios. Flexible policies are required to deal with high uncertainties involved in the policy making process. For this purpose Walker et al. (2001) developed the concept of Adaptive Policy Making (APM). Due to the availability of adaptive policies the policy making process is no longer a main hurdle for implementing very long term policies.

4.2.3 Lack of working methods for developing very long term policies

A more important bottleneck for the implementation of very long term policies is the lack of knowledge and working methods. Agusdinate (2008. p.6) indicates that[9] *"[…] the importance of addressing uncertainties that stem from, for instance broader time scales, has been widely acknowledged. Lempert et al. argue that quantitative analysis covering time horizons long into the future has been rarely attempted in recent years, not because analysts and decision makers do not deem it important, but more because there has been a lack of credible tools/methods to perform the analysis (Lempert, Popper, and Bankes, 2003)".*

4.2.4 Very long term forecasting methods finally gaining broader interest

The field of *very long term forecasting* is still relatively new. In 1972 the Club of Rome attempted a first quantitative prediction on the potential future of the world towards 2100 (Meadows et al., 1972). The method was based on system dynamic approach, but the gloomy results shocked the world and raised an intense discussion on the validity of quantitative predictions. Rivett (1978, p.35) mentioned that according to a number of sources quantitative methods are only useful up to about 15 years. For longer time horizons scenarios should be preferred which can for instance be developed by applying Delphi Techniques. Influenced by this discussion scenarios remained the most common way of dealing with future uncertainty. Scenarios generally have a time span of 20 to 40 years.

For some major issues such as population, energy, climate change and the rise of sea water levels longer forecasts up 2100 have been developed over the past two decades. To shape a broad view on the future the Intergovernmental Panel on Climate Change (IPCC) developed 40 scenarios amongst four different story lines. The use of more than 4 scenarios is however not recommended and scenarios do not indicate the level of certainly of an outcome. Therefore others such as the International Institute for Applied Systems Analysis (IIASA) prefer to use a probabilistic approach based on systems analysis. The findings of the probabilistic approach are generally indicated by graphs showing the mean and confidence intervals of a parameter. A new robust Long Term Policy Analysis (LTPA) method has been developed by the RAND Corporation to deal with deep uncertainty and long time horizons. The method deals with uncertainty by exploring the future in order to find robust solutions amongst large ensembles (hundreds to millions) of scenarios referred to as "landscapes of plausible futures" (Lempert et al., 2003).

As indicated the long term perspective is gaining interest and there are a number of techniques available to describe the future. For each very long term policy a clear evaluation of the available techniques should be made in order to define the best suitable approach.

4.2.5 Integration of relatively small and still developing research disciplines

This research project involves many different research disciplines such as: Freight Transport Modelling, Transport Economy, Intermodal Transport, Civil Engineering, Naval Architecture, Policy Making, Forecasting and Econometrics. Many of the (sub)fields are relatively small and/or not yet fully developed. For example *"Compared to passenger transportation modelling, the field of freight*

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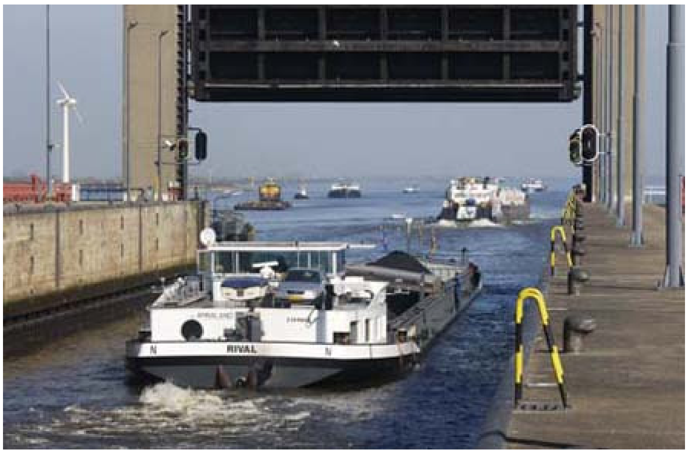
[9] The original text (Lempert et al., 2003, p. xi) *"Analysts and decisionmakers are neither ignorant of nor indifferent to the importance of considering the long term. However, well-publicized failures of prediction—from the Club of Rome's "Limits to Growth" study to the unexpected, sudden, and peaceful end of the Cold War—have done much to discourage this pursuit. Systematic assessments of the long-term future are rare because few people believe that they can be conducted credibly"* does not explicitly mention a lack of credible tools/ models.

transport modelling is relatively young and developing quickly into different directions all over the World" (Tavasszy, 2006, p.1); and *"Within the transport literature, inland water transport has received relatively limited attention"* (Jonkeren, 2009, p.13). Within the field of Civil Engineering the inland waterways are generally perceived less interesting than the international port sector and do not obtain the attention it deserves. The same holds for the field of Naval Architecture where inland vessels are perceived less interesting than seagoing vessels. Adaptive policies have been discussed by Marchau et al. (2007) for road, rail and airport infrastructure, but not for inland waterways. The field of futures research/ foresight is still developing and not very coherent. Though comprehensive books on forecasting are available (Armstrong, 2001, pp. 633-939) no standard work on trade, traffic and transport forecasting has been found. Considering the above it can be concluded that many different (sub)fields of relatively small or less developed disciplines are involved and have to be integrated.

4.2.6 Challenges with respect to very long term valuation and discounting

In addition to the aspects mentioned in the previous section there are three challenges with respect to the development of a very long term evaluation methodology that require special attention. These issues are related to the valuation of the various policy outcomes of interest, the value of time, and the applied decision criteria. For the valuation of the outcomes of interest the government and Rijkswaterstaat have jointly developed guidelines such as the OEEI and OEI[10]. It is however not clear if the OEEI/OEI methodology is also suitable for the evaluation of very long term policies. Secondly there is an issue with the methodology for discounting the value of time. The OEEI/OEI guidelines apply a fixed discount rate but it is questionable whether such an approach is still desirable since cash flows in the far future have virtually no discounted value today. For evaluating very long term policies alternative options such as diminishing discount rates or an increased valuation of the outcomes of interest may be more appropriate. This should also be taken into consideration. Finally a different decision principle might be required for the evaluation of the policy alternatives. On the very long term maximization of the outcomes of interest may no longer be the preferred selection criteria and other procedures such as regret minimization should therefore be considered as well. Literature research will be required to cover the three issues mentioned in this section.



4.3 Main objective of the PhD project

Having sketched the background of the project and the desire to take very long term developments over the lifetime of the infrastructure into account in order to improve service quality and reduce future system costs the main objectives of the PhD research project are:

- To develop a model that provides insight in the possible developments of (and on) the main waterway network in the Netherlands up to the year 2100;
- To develop an extension of the model that evaluates the internal and external effects of a proposed policy or a change in the external environment;
- To develop a workable method that can be applied by Rijkswaterstaat to define the very long term effects of various policy alternatives as well as a very long term policy 2100 vision for the management and development of the Dutch waterway system.

The first objective requires a description of the external effects (exogenous variables) as well as a description of the waterway system and its users. The second objective requires insight in the outcomes of interest for the asset manager. Finally the third objective requires insight in the preferred valuation principles and decision criteria that can be applied to evaluate the various policy options.

[10] OEEI stands for "Onderzoeksprogramma Economische Effecten Infrastructuur" (English: "Research program Economic Effects Infrastructure") and OEI stands for "Overzicht Effecten Infrastructuur" (English: "Overview Effects Infrastructure").

5. CASE RIVER MEUSE

5.1 Introduction and objective

As shown in section 4 a strategy to substitute the infrastructure has to be based on objective information, and on insight in the adaptation and use of the water system in time due to changes in climate, infrastructure and policy. The objective information is input for the development of several scenarios, and for the predictions corresponding to these scenarios. Last part of the development of a strategy is to weight the outcomes. Selection of scenarios and weighting of outcomes has to be based on a comprehensive view on the water system.

In order to generate some feeling and insight developing a strategy, to concentrate the scope and to reach insight in the possible outcomes, a case study has been carried out. The subject of the case study is to develop and compare two scenarios for the weirs in the Meuse: refurbish and maintenance of the weirs in the river Meuse, or renew the whole weir system. In case of renewing the objective is to find out whether the cost-optimal number of new weirs may deviate from the existing number. The case is realistic in the context of the ageing of the existing weirs.

For the case study Meuse the steps in developing a strategy mentioned above are simplified, to get insight, and to obtain an example for a proper discussion with respect to benefits of the long term approach. The case study is meant to get discussion with the stakeholders, not to give a scientific underpinned result.

5.2 The river Meuse

The Meuse is a rain-river entering the Netherlands from Belgium (Figure 3). At the border the mean water level is about 45 m above mean sea level (MSL). First thoughts about canalisation of the Meuse by building weirs and ship locks take place around the year 1900. Starting point at that time was the number of about twenty weirs, because of the technical possibilities to deal with the maximum water head of 2m per weir. During the planning period the technical possibilities and practical applications increased. In the period between 1920 and 1935 seven weirs have been built in the Meuse, combined with ship locks, to be able to use the river for shipping, even in dry periods.

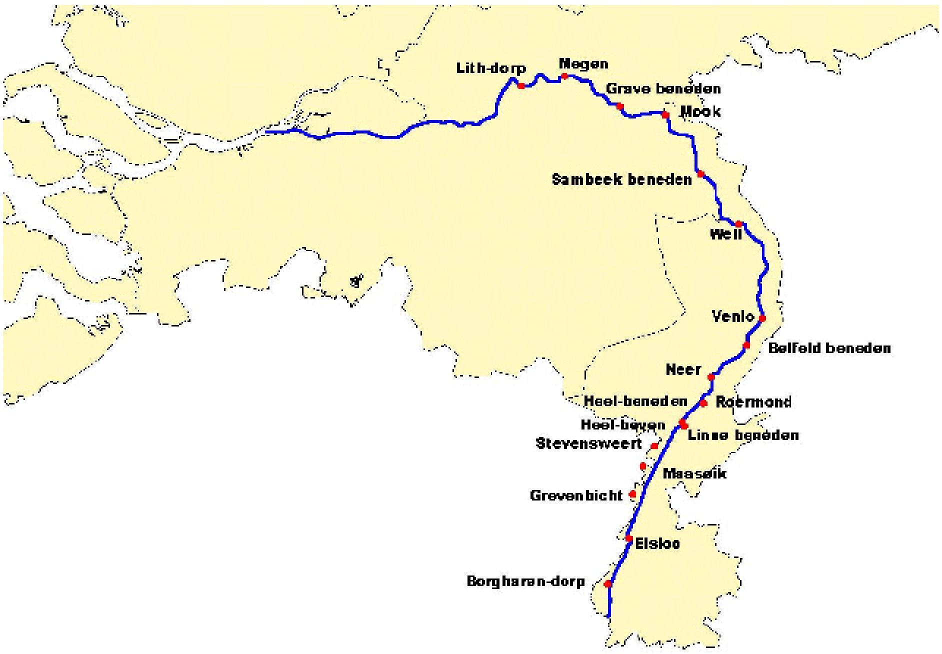


Figure 3: Meuse in the southern part of the Netherlands

In 1993 and 1995 the discharge of the Meuse was very high. The last time it reached a comparable level was in 1926. Much damage occurred, so the Dutch Government decided to built dikes to protect the villages in the upstream Meuse-area. In Figure 4 an overview is given from the high-water levels from the border until the most seaward weir of Lith (blue). These levels are used for safety reasons to assess dike heights and dike strengths. In common the dike heights along a small river like the Meuse will be about 0,5 m above the high water levels. The other line in the Figure 4 (in red) gives the weir water levels at low water regime. Between kilometre 16 to 62 the ships are using a canal running parallel to the river, so no weirs were built in that part of the Meuse.

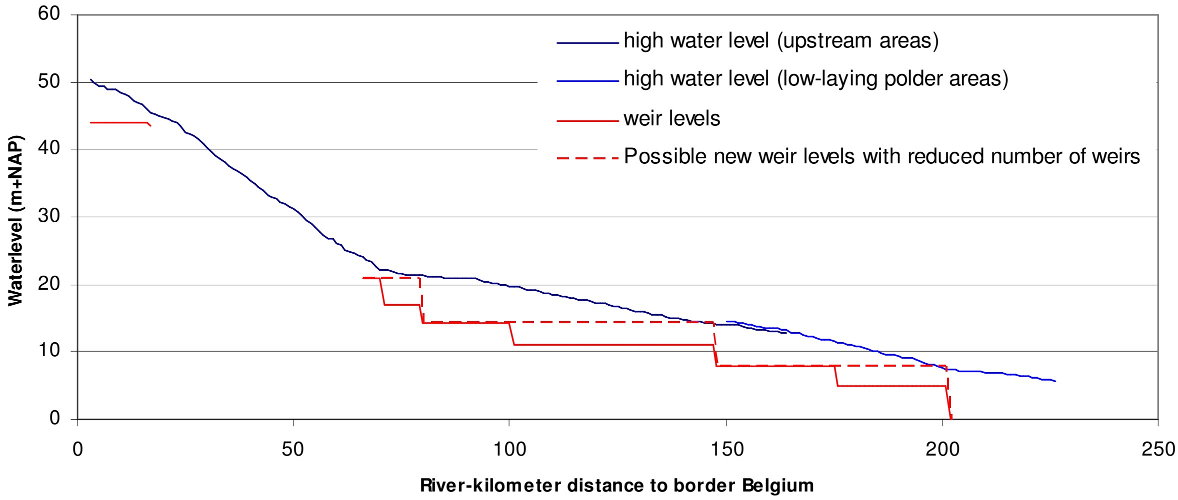


Figure 4: Water levels during high water (blue) and during periods operated by weirs (red)

5.3 Approach and starting points

To simplify the case, first of all only a part of the Meuse is taken into account: the lowest part of the Meuse (from Linne, kilometre 70, until Lith, kilometre 201) in which are six weirs are situated. Secondly, only the costs are taken as a criterion to evaluate whether a scenario is optimal. Thirdly, substitution is assumed to be required at the same year. End last but not least, we assumed the possible reduction of the number of weirs will effect daily and average water levels and groundwater levels, but effects on agricultural use of the influenced area has not been taken into account.

Two scenarios have been evaluated: A) to lengthen the residual lifetime by refurbishing the existing weirs, and by intensify maintenance; B) to substitute the existing weirs by new ones, in which the number of new weirs has been varied.

Objective of the case study is to (virtually) decide about which scenario seems to be the best option for the river Meuse. The approach is to compare the costs of the two scenarios.

General starting points of the case study were:

- The present number of weirs in the considered part of the river Meuse is 6. Each weir will be refurbished and intensively maintained (scenario A) or renewed (scenario B).
- When the number of weirs in scenario B is less then 6 the other weirs has to be destructed.
- Use of the net present value approach (NPV) to integrate the costs of substitution and the cost of maintenance; discount rate is taken as 2%, so the yearly costs has to be increased by a factor 50[11].
- Costs will be calculated from the year the decision is taken and carried out. The planning of the most cost-effective year to choose for scenario A or B is not considered.

In case of scenario A the costs are the sum of the refurbish costs and the discounted yearly costs such as maintenance costs. In case of scenario B the refurbish costs will be renewing costs. Other costs components have to be distinguished for scenario B as well. Demolishing costs in case of less

[11] The factor 50 is defined as the perpetuity of the annual maintenance costs. The perpetuity is an annuity in which the periodic payments begin on a fixed date and continue indefinitely. It is sometimes referred to as a perpetual annuity. The value of the perpetuity is finite because receipts that are anticipated far in the future have extremely low present value (present value of the future cash flows). The value of the everlasting cash flow can be defined by dividing the fixed annual cash flow by the interest rate. In this case 1 million divided by 2% is 50 million. This is a simple approach since in reality the lifetime is not infinite. This has to been taken into account, but it is neglected in this case study. For a 100 year economic lifetime of the objects the discounted value should be 44 instead of 50 times the annual cash flow.

than six weirs, and costs of dike heightening, because due to the removal of weirs the dike heights are locally insufficient. In Figure 4 (dashed red line) a possible situation is given when the weirs are removed at Linne (km 70), Belfeld (km 100) and Grave (km 175). It is obvious the dike heights are locally insufficient. In case only one huge weir would be built at Lith (km 201) for the whole considered part of the Meuse, the weir level has to be sufficient for navigation up to Linne (km 70). This leads to a weir level of about 20m +NAP, so the dikes on both sides of the river have to be heightened over a length of about 130 km.

So for both scenarios the total costs consist of three cost components: the number of weirs to be refurbished or renewed and maintained, the length of dikes along the river which have to be heightened due to less then the existing number of weirs, and the demolish costs of the removed weirs. The considered cost elements of those three components are: weir construction costs, or demolish costs, maintenance costs, operational costs, costs of delay of shipping, and costs of heightening the dikes along the Meuse.

Construction, demolish and dike heightening are costs which have to be made once. Maintenance, operational costs and reduced delay of shipping are yearly costs which have to be discounted. Costs of dike heightening is depending on the construction length and on the average dike heightening. Costs of demolish is depending on the reduced number of new weirs with respect to the present number of six weirs. In formula :

$$NPV_{Meuse\ Weirs} = N\,(C_c + discountfactor(\,C_m + C_o + C_s) + L_d h_d C_d(N) + (6-N)C_{des} \qquad (1)$$

In which:

L_d is the length of required dike strengthening, h_d is the average required dike heightening, and C_d are the dike heightening costs, N is the number of weirs, C_c are the costs of construction or refurbish per weir, C_m are the yearly maintenance costs, C_o are the yearly operational costs, C_s are the delay costs of shipping per weir, and C_{des} are the demolishing costs per weir. In scenario A the number of weirs N is fixed at six, in scenario B the number of weirs is a variable.

Cost element	Scenario A refurbish existing weirs	Scenario B New weirs	remarks
Costs per weir			
Construction or refurbish	30	100	Including ship locks
Demolishing costs		20	
Maintenance per year	2	1	Existing weirs are old and require more efforts
Operation per year	1	0,5	Existing weirs requires extended staff
Shipping costs per year	1	1	Based on 5000 ships per year and 200€ cost passing a weir/ship lock
Costs to other infrastructure			
Dike heightening/km/m (total of both sides)		2	Differs as a function of the number of weirs: 1: 260 km, average +5 m 2: 140 km, average +1,5m 3: 20 km, average +1,0 m 4: 10 km, average +0,5 m 5 or 6: no dike strengthening

Table 1: Starting points for case Meuse (costs in M€)

5.4 Calculations, conclusions and discussion

In Table 1 all variables has been roughly valuated to calculate the net present value of the two scenarios. The result of the calculations are presented in Figure 5 and Table 2. Scenario A leads to net present values of about 1400 M€. When in scenario B the same number of new weirs will be built the NPV is about 1400 M€ as well. When the number of new weirs in scenario B is reduced the NPV reduces als well. Only in the case of one very huge weir at Lith, with a crest height of about 20m above MSL, the costs explode. This option requires dike strengthening along the Meuse of about 130 km at both sides with an average heightening of about 5 m, which is very costly.

In this specific case for the river Meuse it appears that a number of three weirs in scenario B is more optimal than maintain the present situation of scenario A with six weirs. This conclusion is depending on the validity of the simplifications and the assumed costs per element. Nevertheless it shows the fact that a decision about renewing ageing structures is a possibility to think about the asset in a (river)system.

More in general we conclude:

- The case study gives insight in the effects of different scenario's ore options, with respect ot the chosen criteria. It contributes to the proposed strategy to consider more than one scenario. A rough analysis may be enough to give insight in the validity of options.
- The suggestion that building new hydraulic structures in place of the old ones is the best option is not supported by the case study.
- For ageing structures it is beneficial to evaluate the decisions about maintenance, refurbish or renewing by comparing some scenarios. The net present value offers the opportunity to compare different kind of cost elements in time.

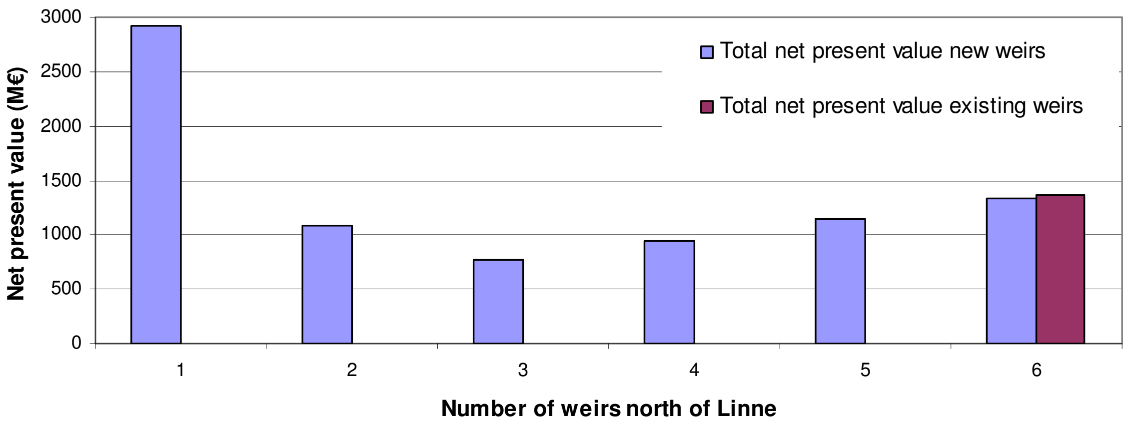


Figure 5: Comparison of scenario's for a different number of weirs in the Meuse

Number of weirs	Scenario A refurbish existing weirs	Scenario B New weirs
1		2924
2		1088
3		771
4		945
5		1139
6	1368	1343

Table 2: Results of calculations for case Meuse (net present values in M€)

6. AWARENESS AND SUPPORT

The development of the methodology and long term strategy is likely to follow the ADKAR model which stands for: building *awareness*, creating *desire*, developing *knowledge*, fostering *ability* and *reinforce* changes in the organization (Hiatt, 2006). At the moment (Spring 2010) the process is still in the phase of building awareness and creating desire.

As explained in the previous parts, making a long term strategy seems to be sensible. In the real world it can be complicated to implement an 'obviously good idea'. The following paragraphs address several possible obstacles and possible ways to deal with them.

6.1 Interference with present policies

For example: A long term strategy (50-100 years) may interfere with present or 'semi-long term' policies (5-10 years), supported by politicians. Or maybe the long term strategy doesn't interfere with present policies, but can still be regarded as a threat to decisions that are already made or are soon to be made.

In order to reduce that (alleged) threat, it may be wise to involve policy makers in an early stage. They may be convinced that a long term strategy supports them. Probably it would be best if they accept the long term strategy as their 'own' tool.

6.2 Actors involved

Many actors are involved in infrastructural planning. If one decides to build new infrastructure or reconsiders the use of infrastructure and its surroundings, many people, organisations or civil interest groups tend to have an interest. In the present society those interests cannot be neglected and should not be neglected. One will have to deal with them properly if one wants to have the strategy accepted.

Early in the process one will have to choose a working process. In fact there are two main options:

1. To include as many actors as possible, even before any research is executed.

advantages	**disadvantages**
Actors feel involved and are more likely to participate	It is a complex process. Much time and effort needed for coordination
Less effort is needed in a later stage of the project	It is difficult to make decisions
Problems and wishes of other actors are identified in an early stage	Not all actors may want to follow the same procedure
Information of other actors can be useful	There is a possibility that others will delay or even stop the process.
Lessons can be learned from other actors	
You can share some of the work	

2. To do research with a small group of people within one organisation. Once you have a first result, you share it with other actors.

advantages	**disadvantages**
You can focus on the content, before you have to dive deep into a coordination process.	It will be more difficult to involve other parties in a later stage. Even if the plan is good, if it is '*not invented here*'…..
Decision making process is simple	Plans may have to be adjusted in a later stage according to wishes of other actors
	You can not use the experience of other actors

Both approaches have several advantages and disadvantages. There is no obviously better choice. For this project we still have to decide which method we choose. For either choice we must try to mitigate the disadvantages as much as possible.

6.3 Mobilizing support

In the preceding paragraphs it is stated that one can decide to involve other actors in an early stage or after some time. A lesson learned from other projects is that mobilizing support at any stage will increase the success of the project. Mobilizing support should be a part of the project approach and it will influence the way one will deal with other actors and how to deal with their interests.

- Support can be mobilized if you can explain the benefits for the actors involved.
- Early involvement of a broad range of actors improves support
- It is also very beneficial to inform people as much as possible.
- Take into account the interest of as many actors as possible

A list of benefits of a long term substitution strategy:

- Benefits for the administrator are:
  - lower costs
  - more efficient planning of maintenance
  - more insight in planning of workload and budget
- Benefits for the policy makers are:
  - better overview of the long term consequences of their policies/ choices
  - better spent money
  - more insight in challenges, robust choices, uncertainties and risks.
- Benefits for other groups with an interest in the infrastructure and its surroundings:
  - Their long term interests can be taken into account
  - Since plans are made further ahead, it is easier to anticipate to changes

7. CONCLUDING REMARKS AND CONSIDERATIONS

In this paper we discussed the need of a strategy to optimize the possibilities for a system upgrade at the moment substitution of old structures is required. Aspects affecting the strategy may be the development of the use of the water system over the coming century, climate change, and the different policies in time to deal with the in time changing problems, etc.

To illustrate the need of a strategy, a case study for the weirs in the Meuse has been discussed. In the early 1900's seven weirs have been built for navigation. We show that substitution one by one is not the only option. Considering different options or scenario's criteria will be required. This shows a strategy may consist of scenario-generation and criteria to weight scenario's, both based on a long term water system development vision.

The PhD project on *'Very Long Term Development of the Dutch Inland Waterway System'*, started in March 2009 to provide a sound knowledge base for implementing the desired very long term asset management approach. The study focuses on the transport function of the water system.

In the real world the development of a strategy, and getting support for it, is much more complex. Especially the case study for the river Meuse is carried out with simplifications, so when other functions and more aspects and criteria would be involved the outcome may deviate. At the moment the explorations will start and no general conclusions are to be made.

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